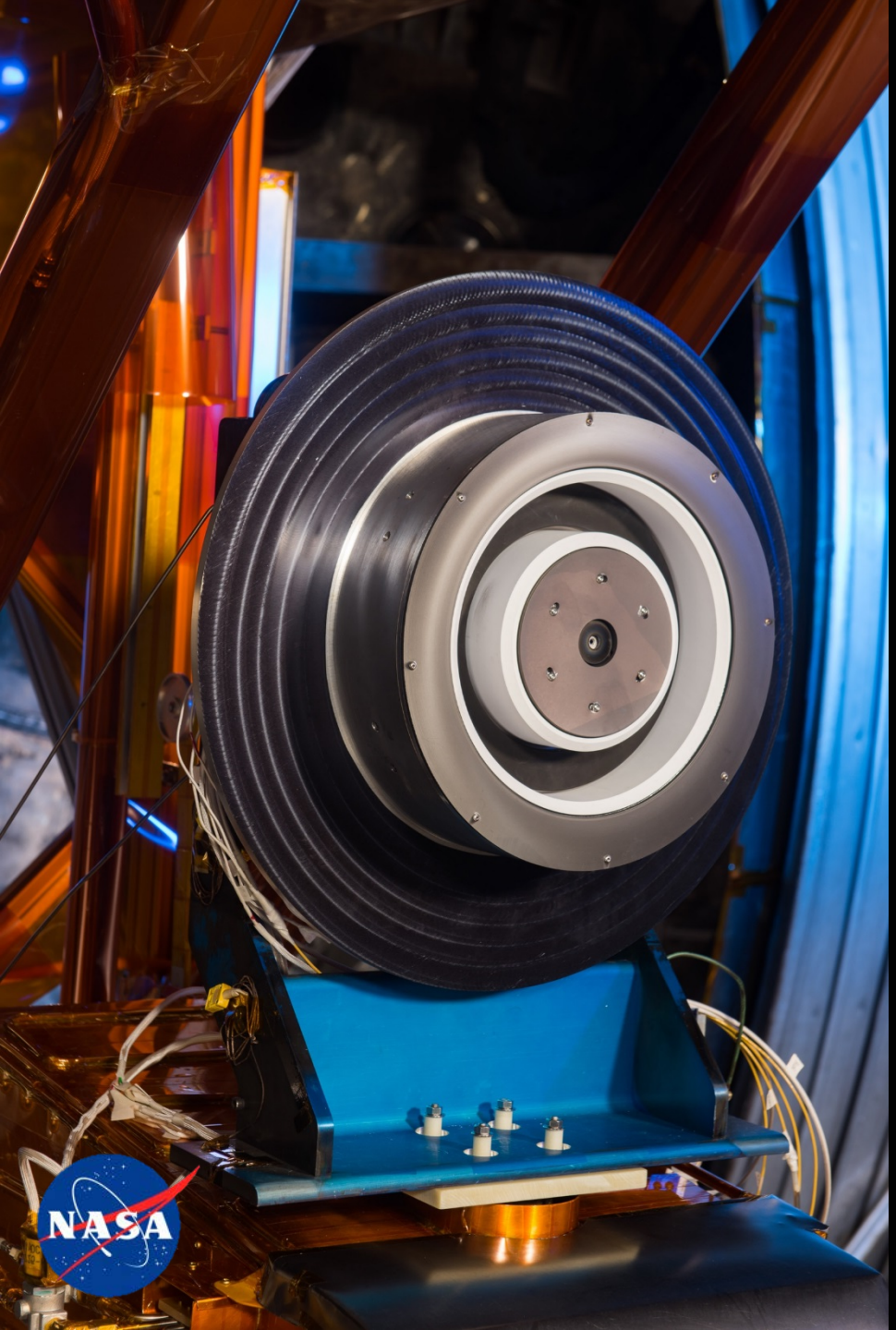


PREPARATION FOR HOLLOW CATHODE TESTING FOR THE ADVANCED ELECTRIC PROPULSION SYSTEM AT NASA GLENN RESEARCH CENTER

Scott J. Hall

Vantage Partners, LLC, NASA Glenn Research Center, Cleveland, OH

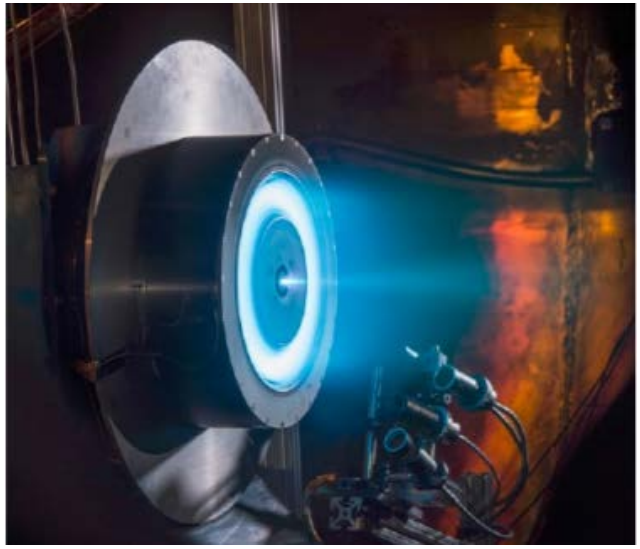
Timothy R. Sarver-Verhey, Jason D. Frieman, and Hani Kamhawi

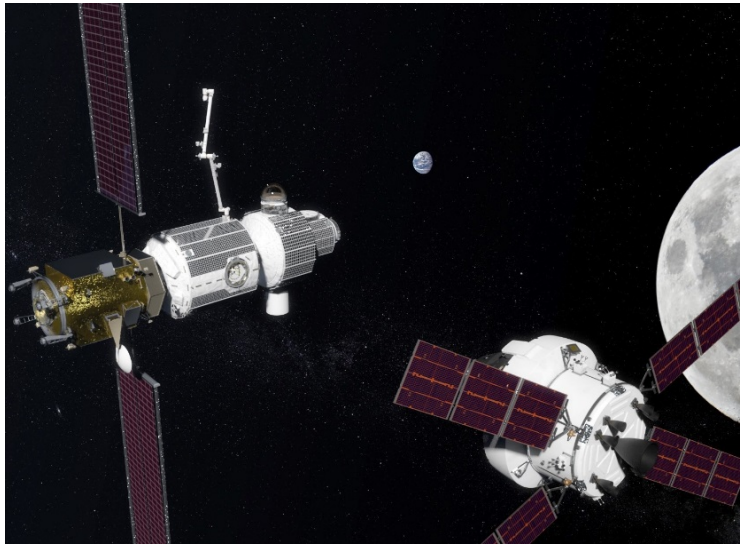
NASA Glenn Research Center, Cleveland, OH

James Myers

Vantage Partners, LLC, NASA Glenn Research Center, Cleveland, OH

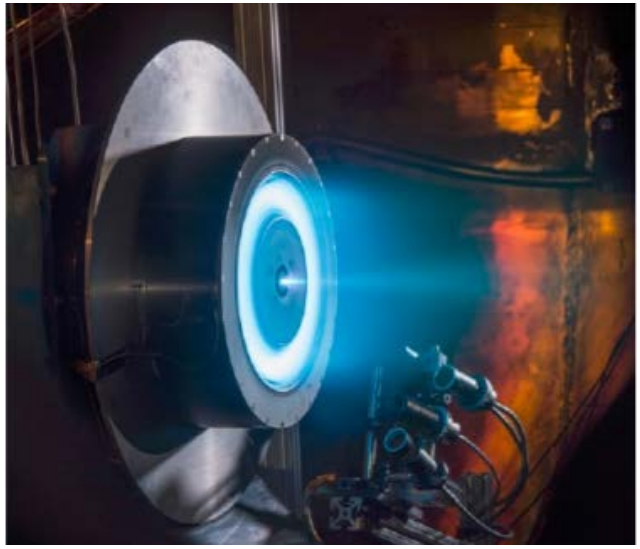
Long-life Hall thrusters need long-life cathodes

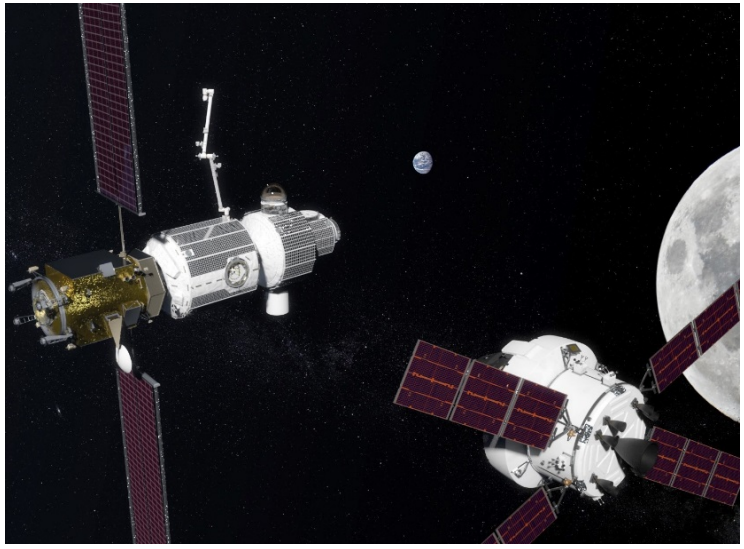




- NASA developing the Hall Effect Rocket with Magnetic Shielding (HERMeS) to serve as high-power EP capability for future missions
  - 12.5 kW magnetically-shielded Hall thruster
  - Example mission: Power and Propulsion Element of NASA's Gateway
- Aerojet Rocketdyne (AR) developing Advanced Electric Propulsion System (AEPS)
  - Leverages HERMeS thruster and cathode development

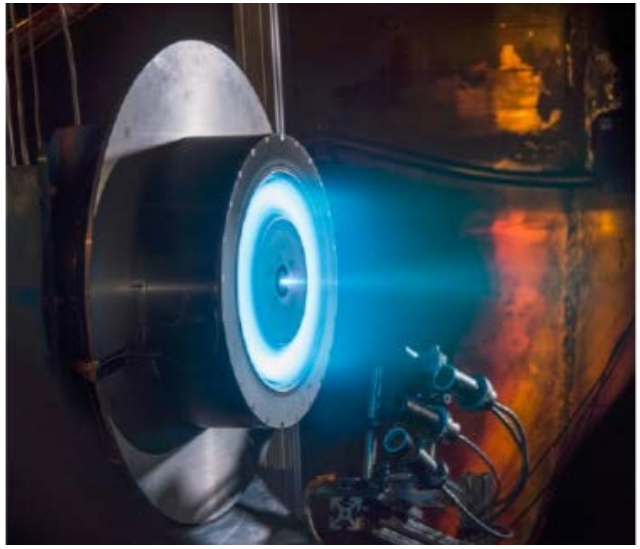
Long-life Hall thrusters need long-life cathodes

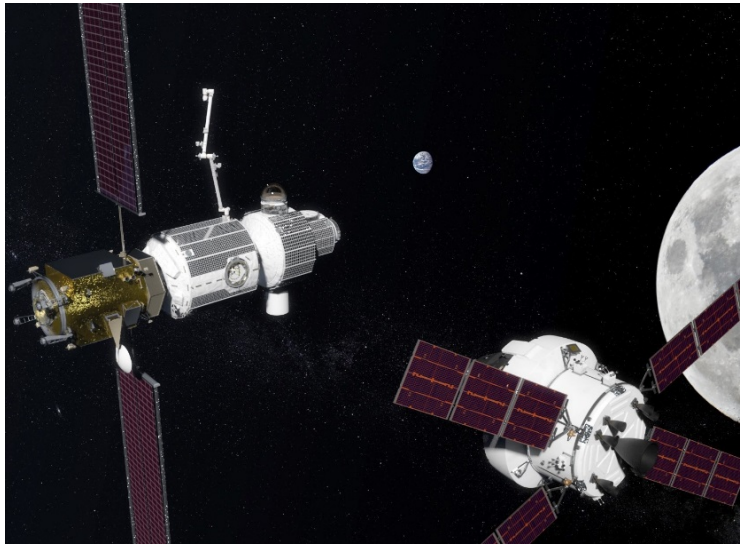




- Targeting system lifetimes of >23 khrs
- Thruster discharge channel lifetime enabled by magnetic shielding

Long-life Hall thrusters need long-life cathodes



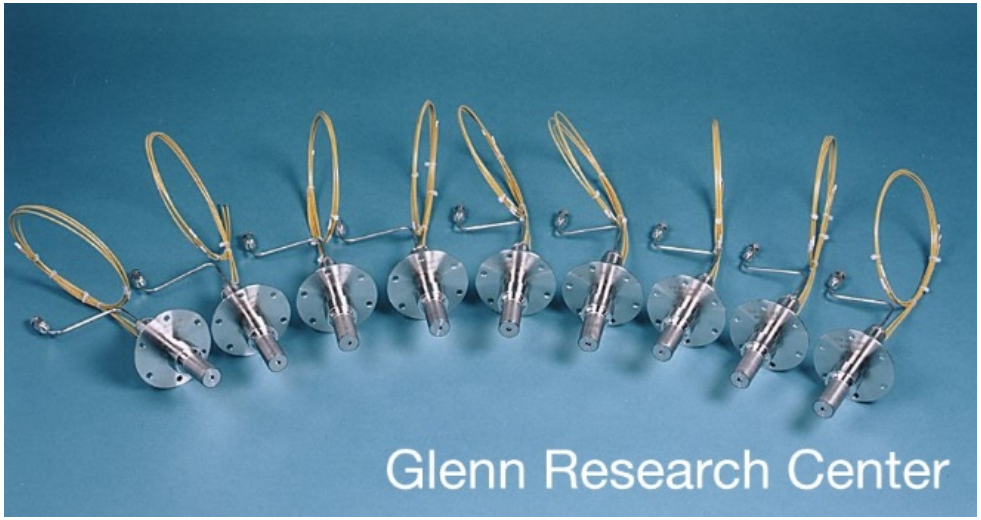


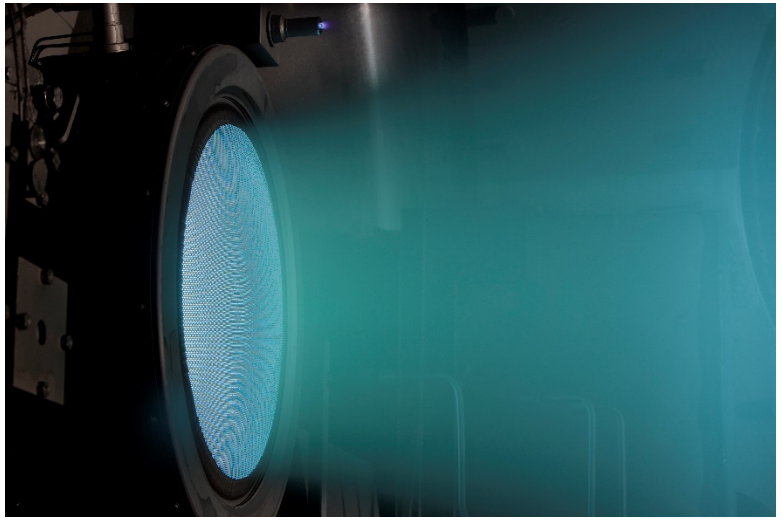
- Targeting system lifetimes of >23 khrs
- Thruster discharge channel lifetime enabled by magnetic shielding

Cathode needs to provide same lifetime, too!

Hollow cathode technology has demonstrated necessary lifetime before

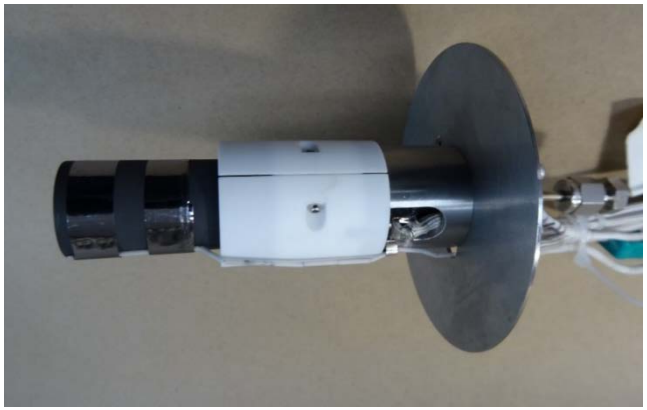
- ISS plasma contactor laboratory model: 28,000 hours (ground)
- NSTAR: 30,000 hours (ground); 46,000 hours (Dawn)
- NEXT: 50,000 hours (ground)





Significant cathode accomplishments during HERMeS development

- Developed two cathode options:
  - BaO (led by GRC)
    - Heritage to ISS PCU, NSTAR
    - Directly based on NEXT DCA
  - LaB_6 (led by JPL)
    - Heritage to H6 and high-current cathode development
- Substantial stand-alone testing of both cathodes:
  - 1800 and 2000 hour wear tests at JPL
  - 2000 hour wear test at GRC

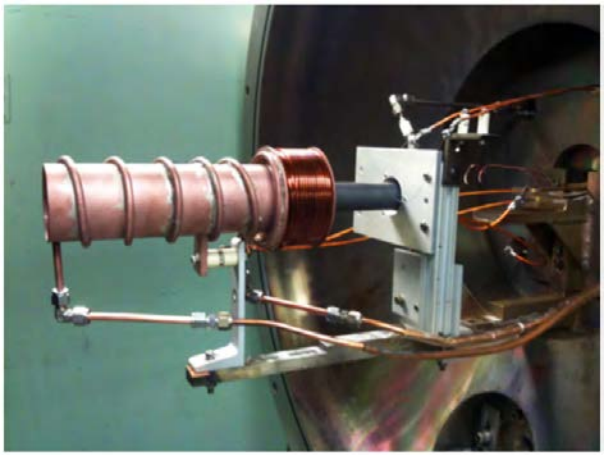


BaO TDU cathode developed by GRC.

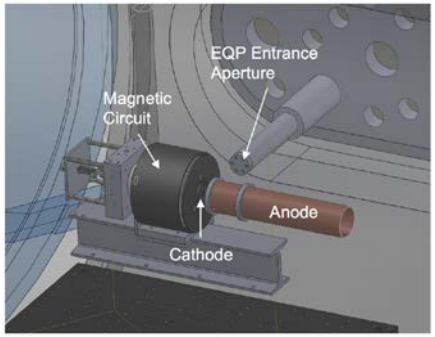
LaB_6 TDU cathode developed by JPL.

Significant cathode accomplishments during HERMeS development

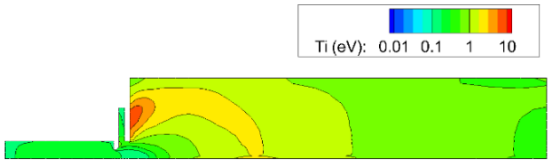
- Cathodes also used during TDU thruster testing:
  - 1700 hours in TDU 1 (GRC)
  - Risk-reduction testing with TDU 2 (JPL)
  - 3000+ hours in TDU 3 (GRC)
- Other risk reduction activities:
  - Cathode ion energy measurements (JPL)
  - Continued refinement of OrCa2D plasma simulations
- AR down-selected to BaO cathode design



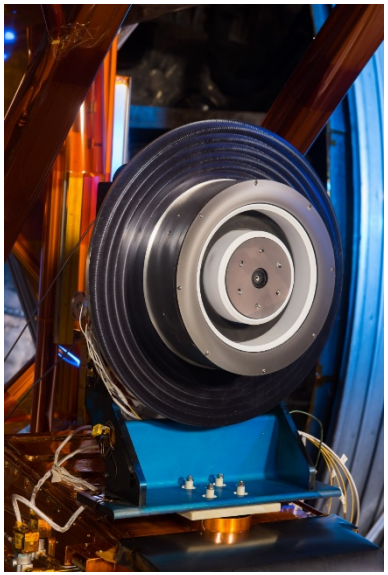
Standalone cathode testing at JPL.



Cathode ion energy measurements at JPL

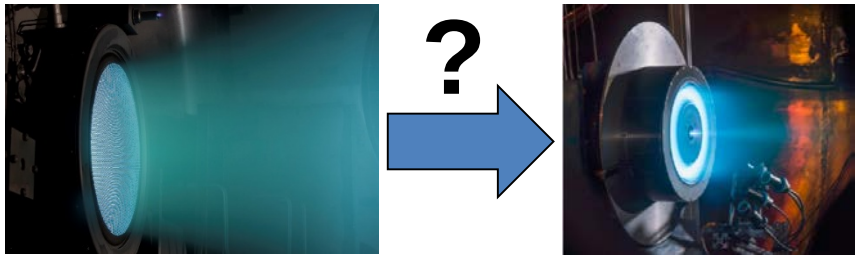


Plasma modeling results from JPL's OrCa2D code.



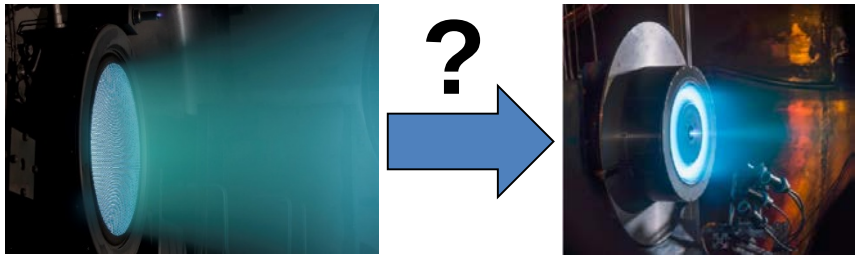
TDU-3 testing in VF-6 at GRC.

Still, some questions linger about hollow cathode lifetime

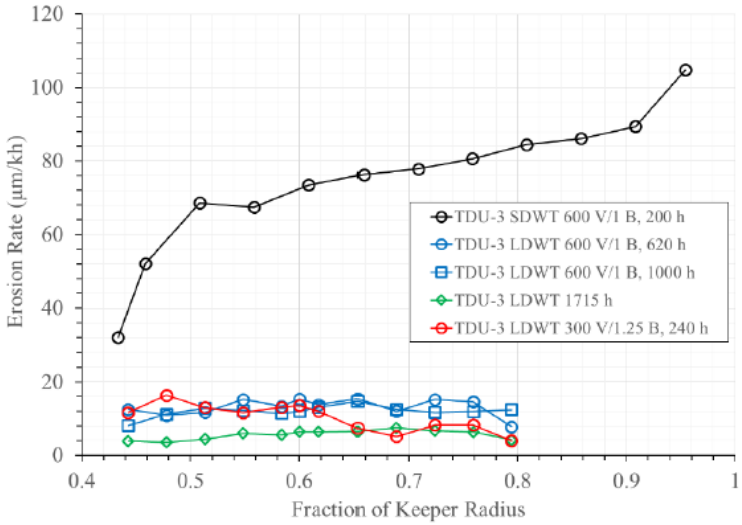


- For AEPS, cathode is centrally mounted
  - Operation environment is different from previous development efforts

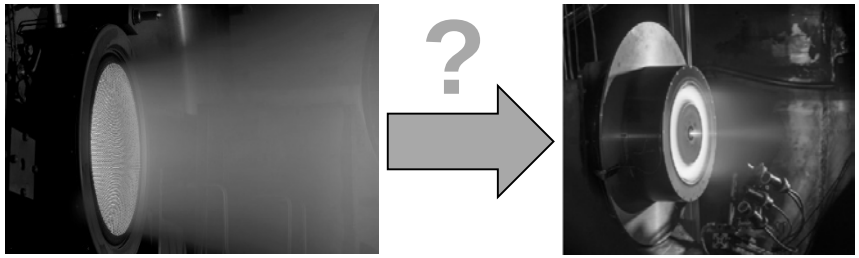
Still, some questions linger about hollow cathode lifetime



- For AEPS, cathode is centrally mounted
  - Operation environment is different from previous development efforts
- Ongoing work includes:
  - Confirming emitter lifetime
  - Understanding oscillation mechanisms
    - Can we replicate without thruster?
  - Understanding cathode environment in thruster
    - Small change in cathode position in thruster resulted in significant change in keeper erosion!

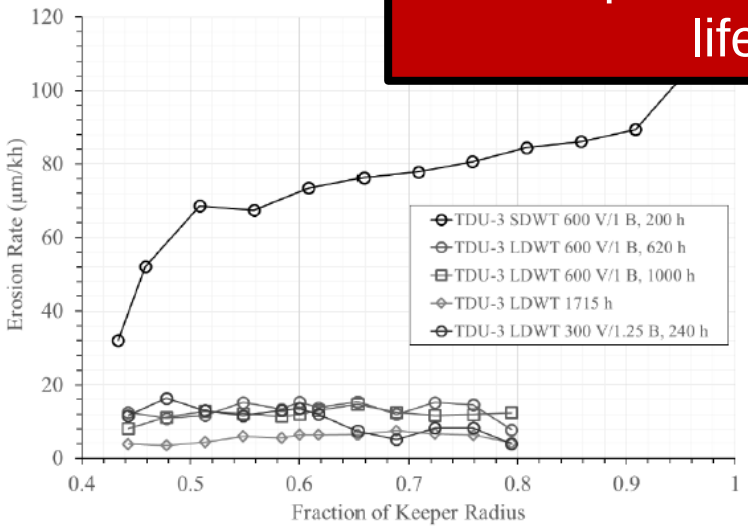


Still, some questions linger about hollow cathode lifetime



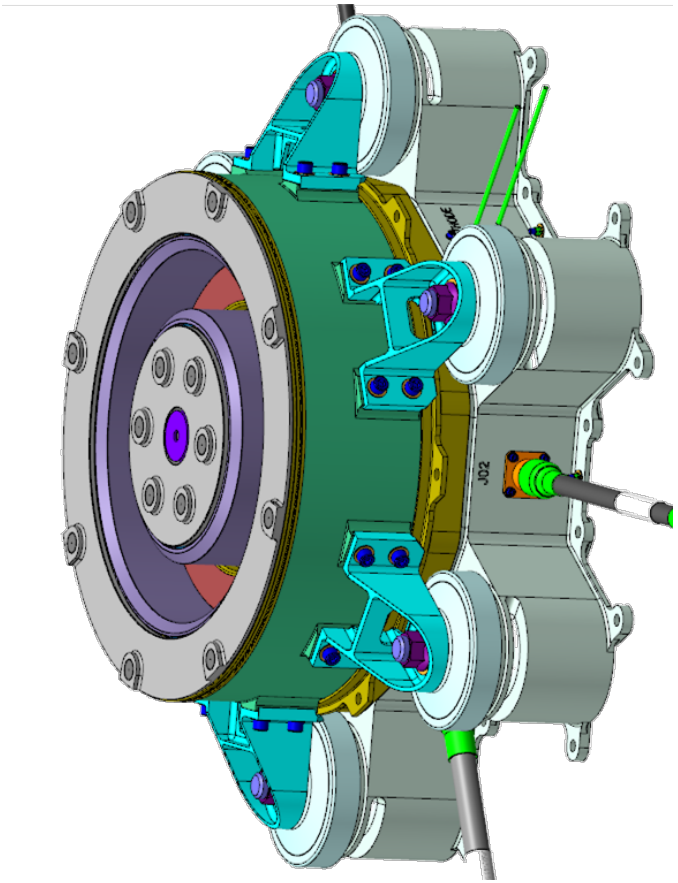
- For AEPS, cathode is centrally mounted
  - Operation environment is different from previous development efforts
- Ongoing work includes:
  - emitter lifetime
  - ling oscillation
  - s
  - replicate without thruster?
  - ing cathode environment in thruster
    - Small change in cathode position in thruster resulted in significant change in keeper erosion!

Long-duration testing is still an important part of cathode development to demonstrate lifetime.



EDU testing will include long-duration testing of both thruster and stand-alone cathode

- Under the AEPS project, long-duration wear testing will be performed on EDU thruster (with EDU cathode assembly)
  - Testing in VF-5
  - Targeting 23 khrs in duration
- Two standalone cathode assemblies (units 3 and 4) will undergo separate long-duration testing:
  - Part of a set of risk-reduction component-level testing
  - EDU-3 will undergo long-duration wear testing (GRC)
  - EDU-4 will undergo long-duration cold-cycle testing (JPL)



GRC preparing for EDU cathode arrival

GRC preparing for EDU cathode arrival

Facility buildup

- Three additional facilities for cathode testing:
  - VF-67
  - VF-17
  - VF-1
- Development of new hardware:
  - Thruster-like magnetic field simulator
  - Cold plate for LN2 cold cycling

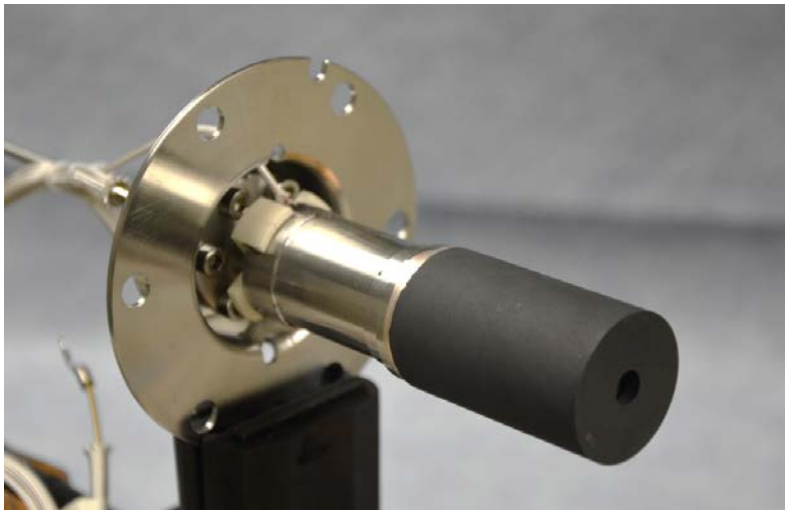
GRC preparing for EDU cathode arrival

Facility buildup

- Three additional facilities for cathode testing:
  - VF-67
  - VF-17
  - VF-1
- Development of new hardware:
  - Thruster-like magnetic field simulator
  - Cold plate for LN2 cold cycling

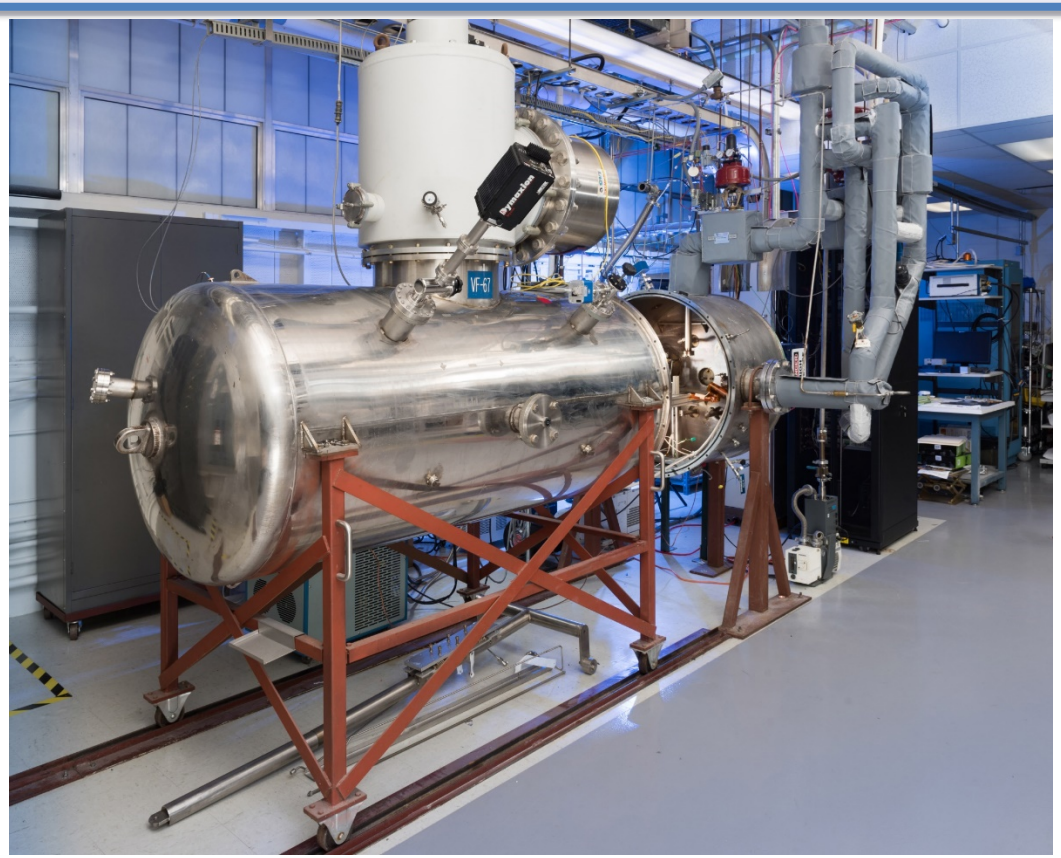
GRC cathode design evolution

- Updates to TDU cathode design:
  - Brazed joints
  - Design simplification
  - Improved emitter retention
  - Keeper assembly geometry match
- New cathode: “Mark II”



FACILITY BUILDUP

VF-67: Long Duration Test Facility



- VF-67:
  - EDU cathode wear and thermal cycle test facility
  - 2.7 m x 0.9 m
  - 8×10^{-5} torr-Xe at cathode

VF-17: Short Duration/Diagnostics Test Facility

- VF-17:
  - EDU cathode characterization and diagnostics
  - 2.1 m x 0.9 m
  - 9.5×10^{-5} torr-Xe at cathode

VF-1: Cathode Development Facility

- VF-1:
  - Cathode development testbed
  - Plasma diagnostics array
  - 4.5 m x 1.5 m
  - 3×10^{-5} torr-Xe at cathode

Even with different applications, facilities feature similar test infrastructure

- All three facilities are being built up with commonality
- Hardware shares heritage to TDU thruster infrastructure
- Each facility will have:

Even with different applications, facilities feature similar test infrastructure

- All three facilities are being built up with commonality
- Hardware shares heritage to TDU thruster infrastructure
- Each facility will have:

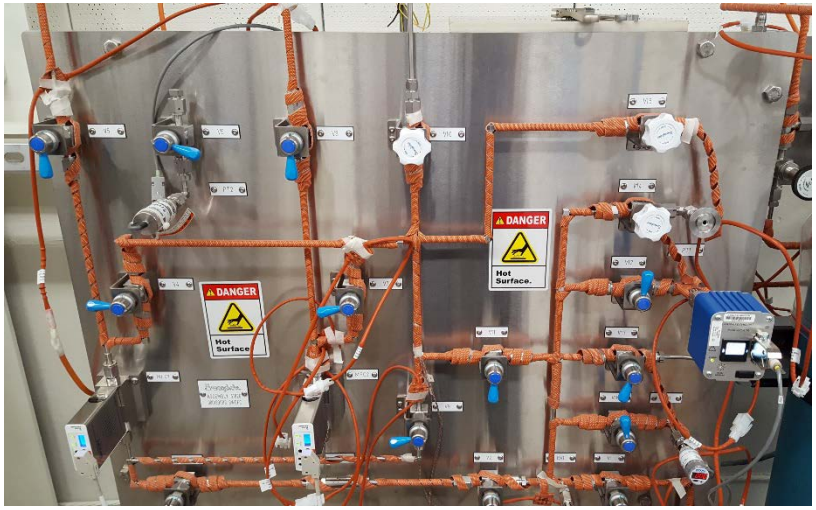
Power Console

Even with different applications, facilities feature similar test infrastructure

- All three facilities are being built up with commonality
- Hardware shares heritage to TDU thruster infrastructure
- Each facility will have:

Power Console

Xenon Feed System

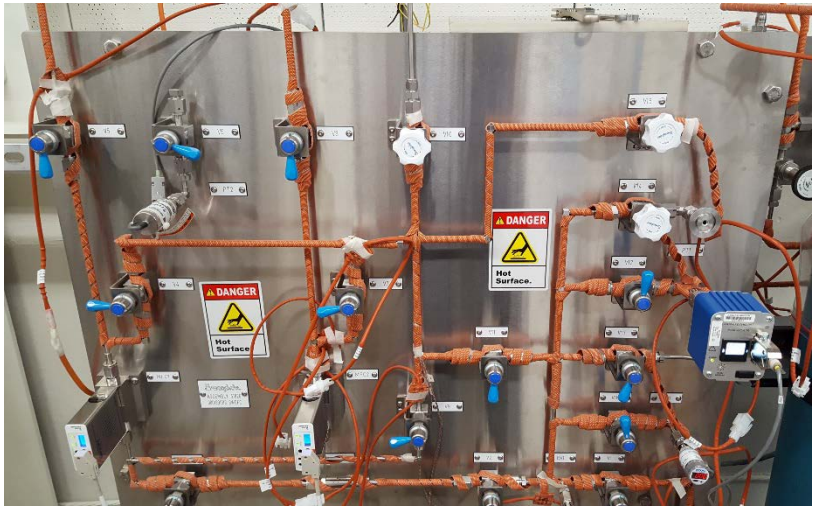


Even with different applications, facilities feature similar test infrastructure

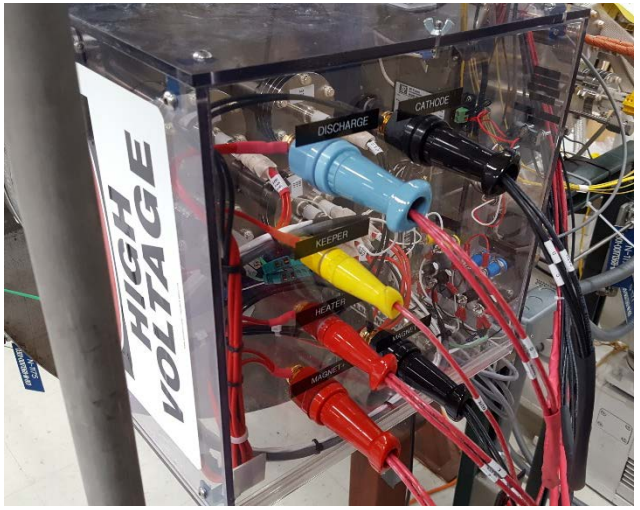
- All three facilities are being built up with commonality
- Hardware shares heritage to TDU thruster infrastructure
- Each facility will have:

Power Console

Xenon Feed System

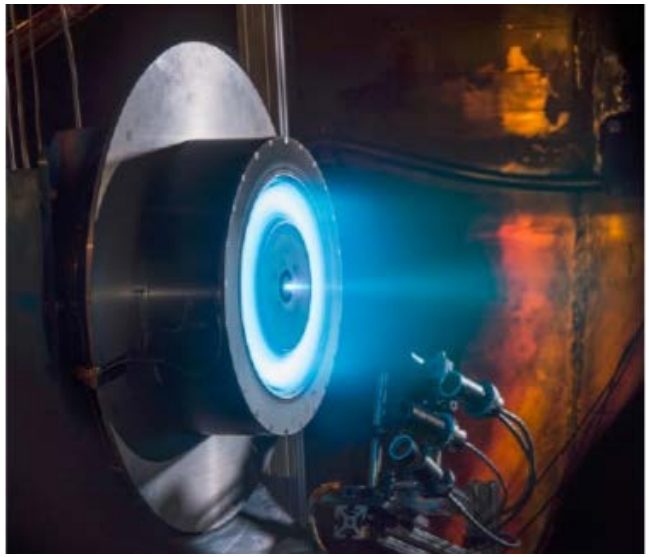


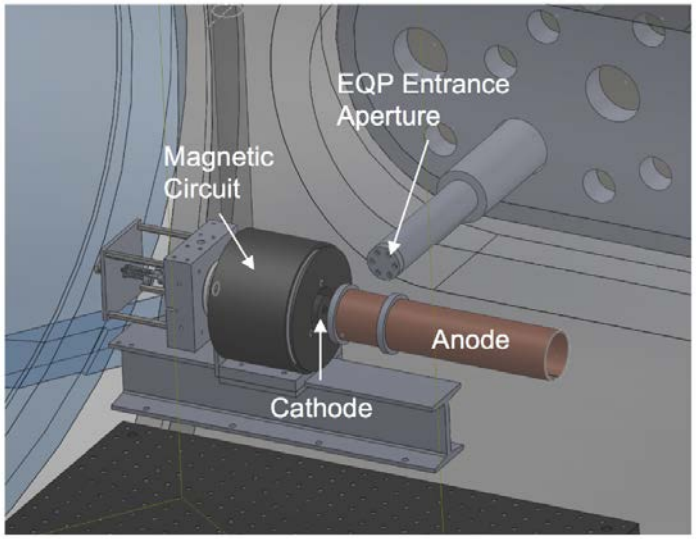
Breakout Box



Thruster magnetic field simulator

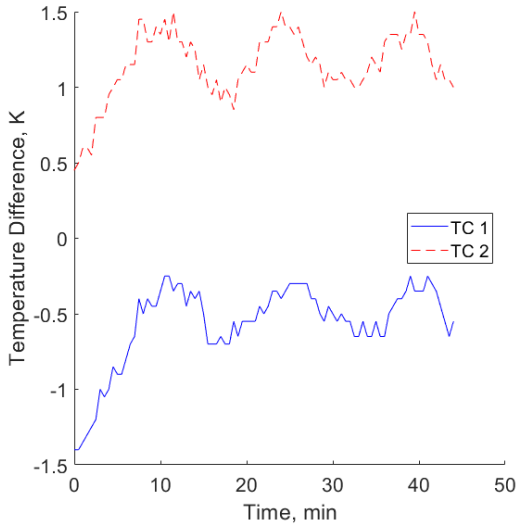
- Developing thruster magnetic field simulator
  - Replicates EDU thruster magnetic field topology in cathode region
  - Similar effort for TDU at JPL
- Magnetic field simulator will be implemented in all cathode tests

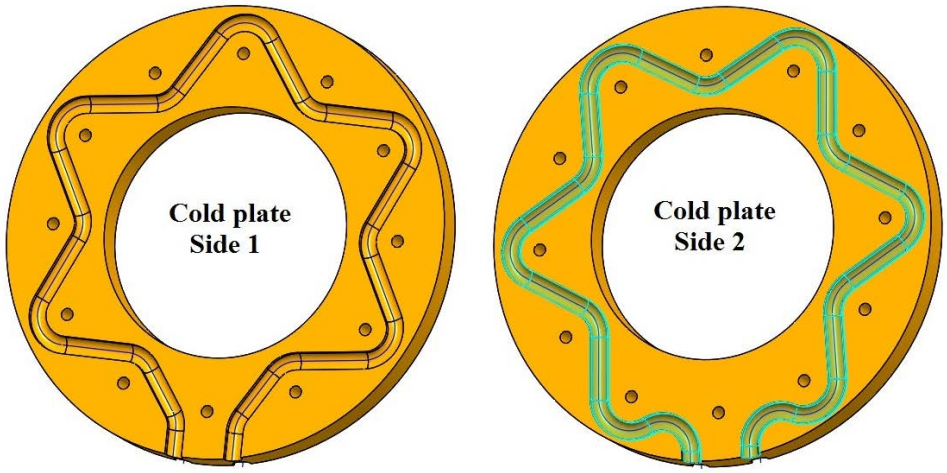




Liquid nitrogen cold plate

- Cold-cycling periodically during long-duration cathode test
- Plate features counter-flow design to provide even temperature
- Will perform thermal cycling of cathode assembly
- LN2 system checkouts are underway in VF-67
  - LN2 valve (bang-bang) was able to hold target temperature to within +/- 3 K

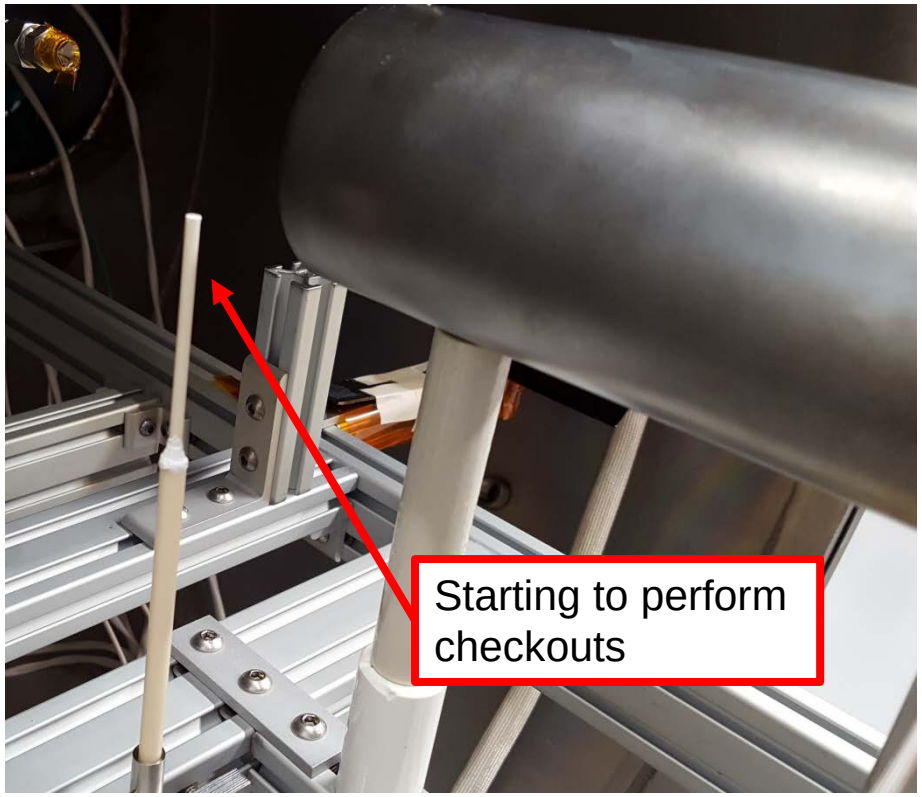




Plasma diagnostics array

- Electrostatic plasma probes:
  - RPA
  - LP
  - Emissive probe
- Fast internal temperature measurement
  - Based on JPL diagnostic
  - Fast stage with fiberoptic sensor; ratio pyrometry
- Exploring other capabilities as well:
  - Optical emission spectroscopy
  - Fast LP
  - Small RPA

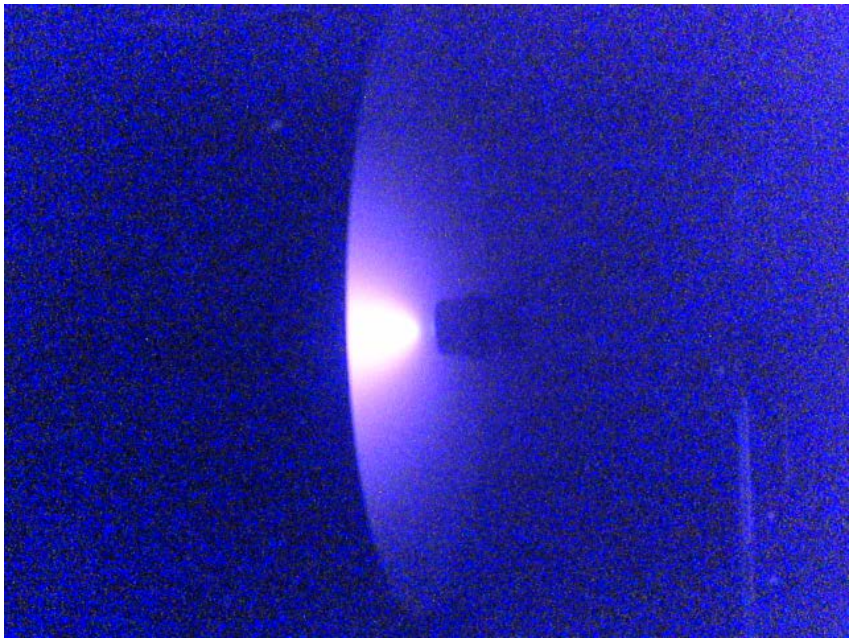
Plasma diagnostics array



- Electrostatic plasma probes:
  - RPA
  - LP
  - Emissive probe
- Fast internal temperature measurement
  - Based on JPL diagnostic
  - Fast stage with fiberoptic sensor; ratio pyrometry
- Exploring other capabilities as well:
  - Optical emission spectroscopy
  - Fast LP
  - Small RPA

Cathode test facility status

- VF-67:
  - Operational. Accumulated approximately 400 hrs of cathode operation.
  - Left to do:
    - Cold plate installation and checkout
- VF-1 & VF-17:
  - VF-1 facility upgrade underway
  - Research equipment buildup ongoing
  - Targeting August for first fire in both facilities



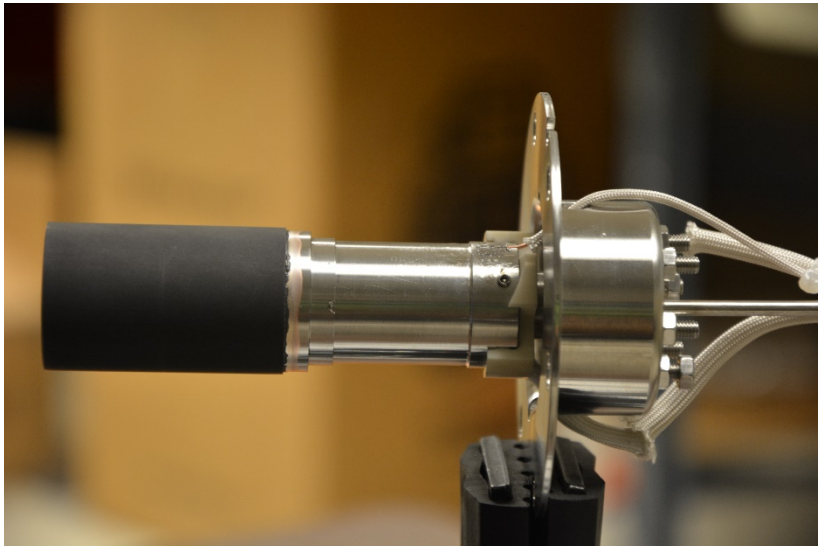
First hot fire of TDU cathode in VF-67

MARK II CATHODE

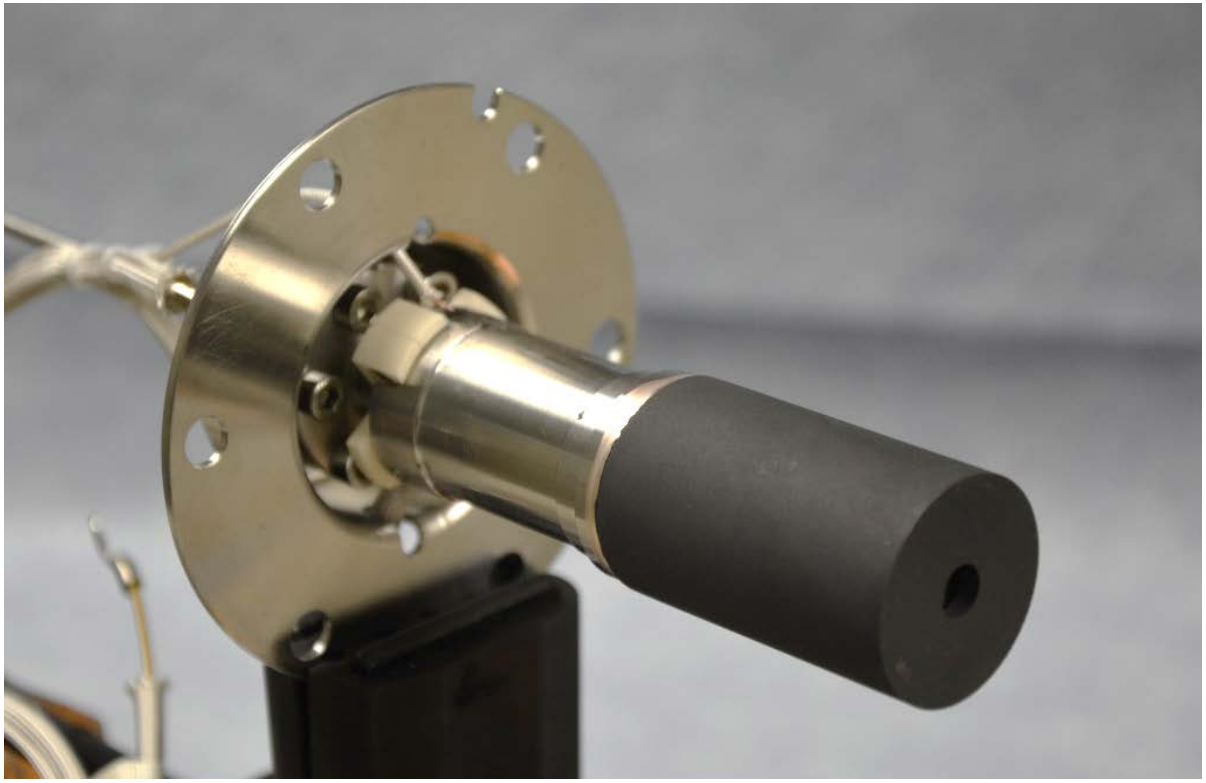
Mark II cathode evolved from TDU design

TDU lab cathode

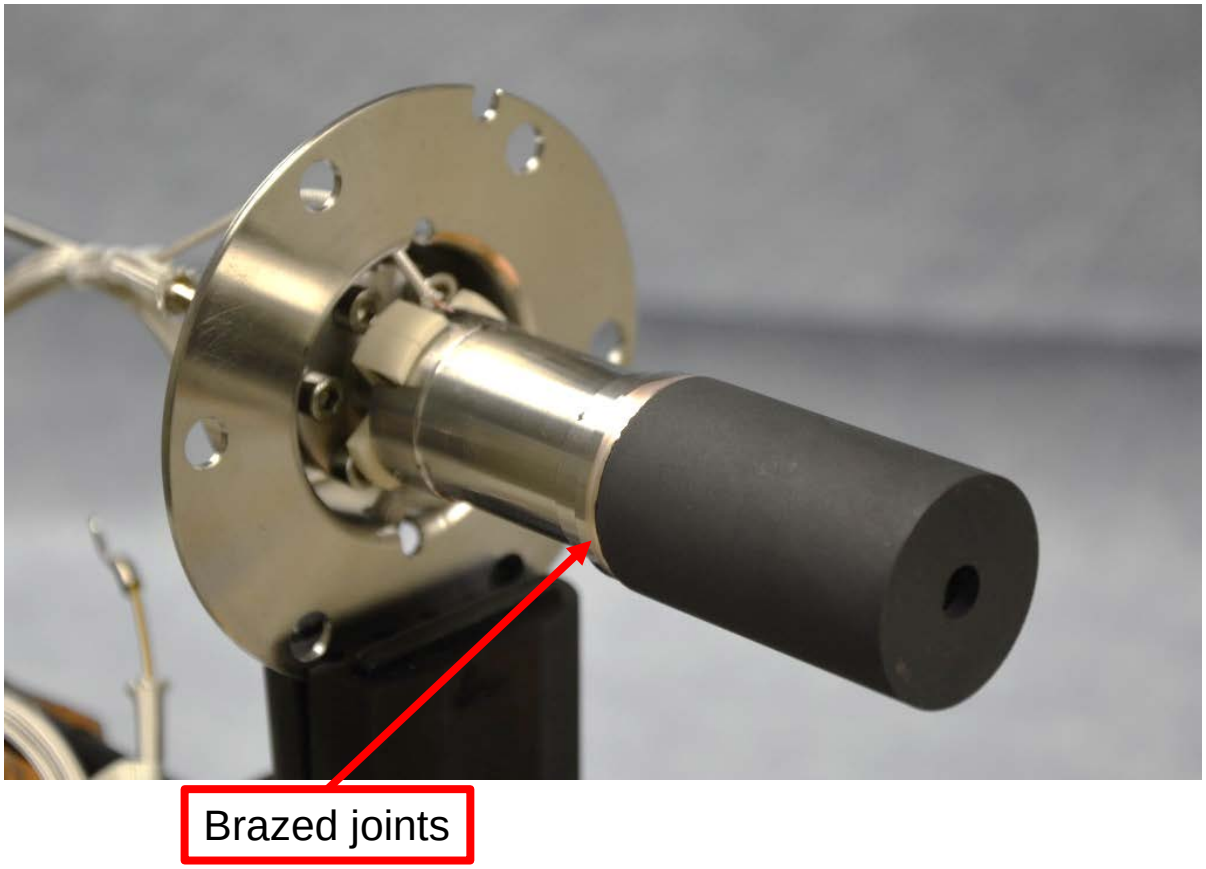
Mark II cathode



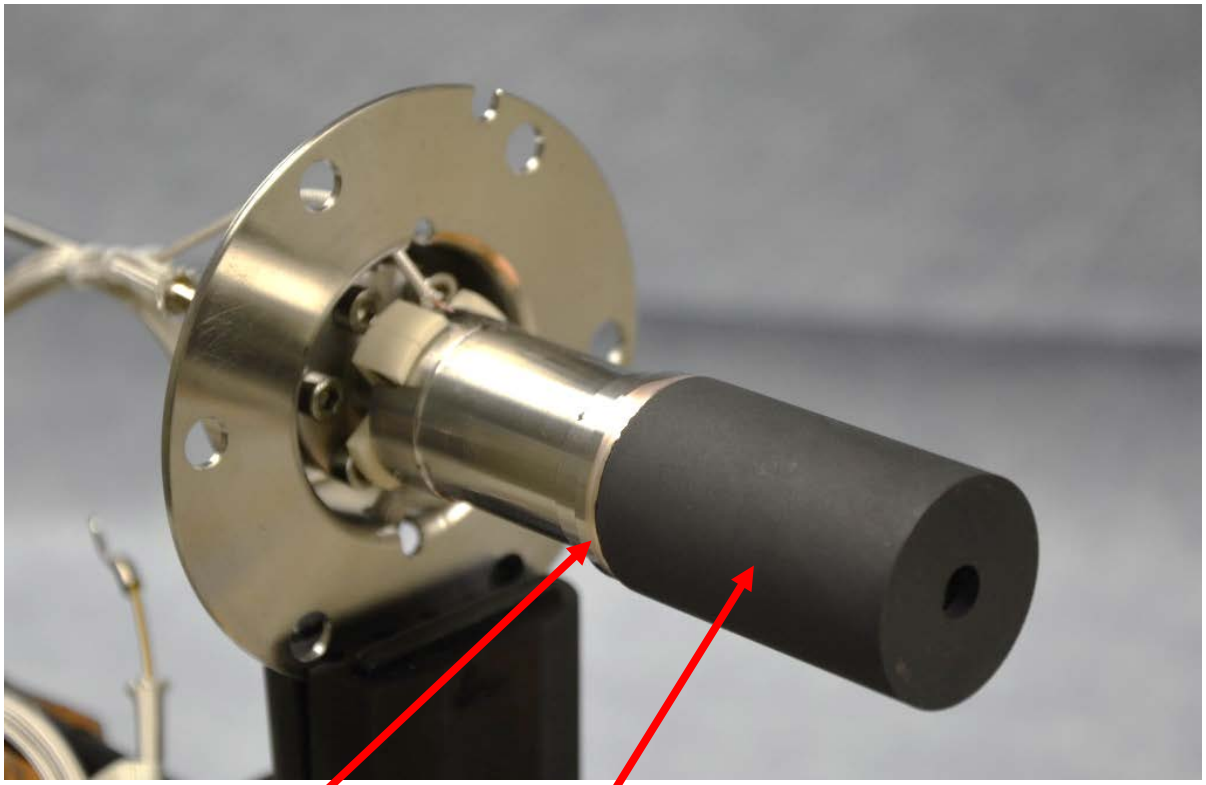
Key design changes of Mark II cathode



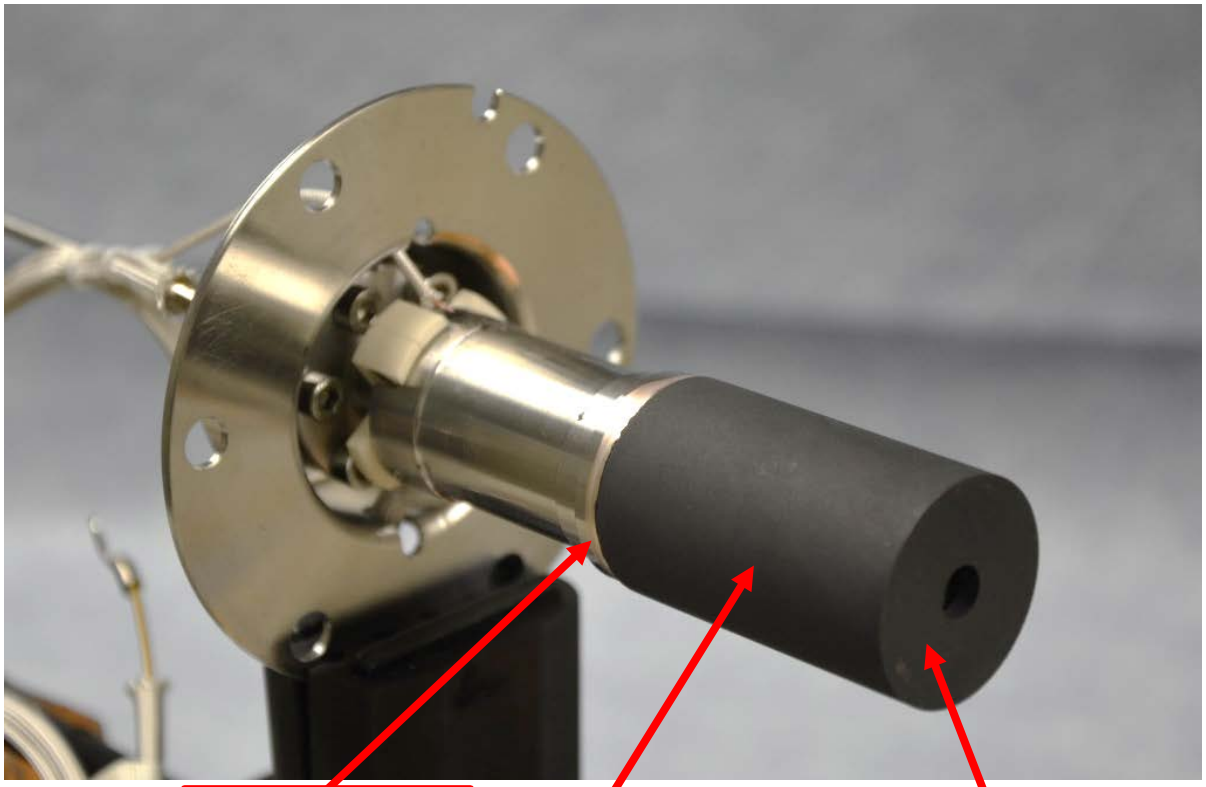
Key design changes of Mark II cathode



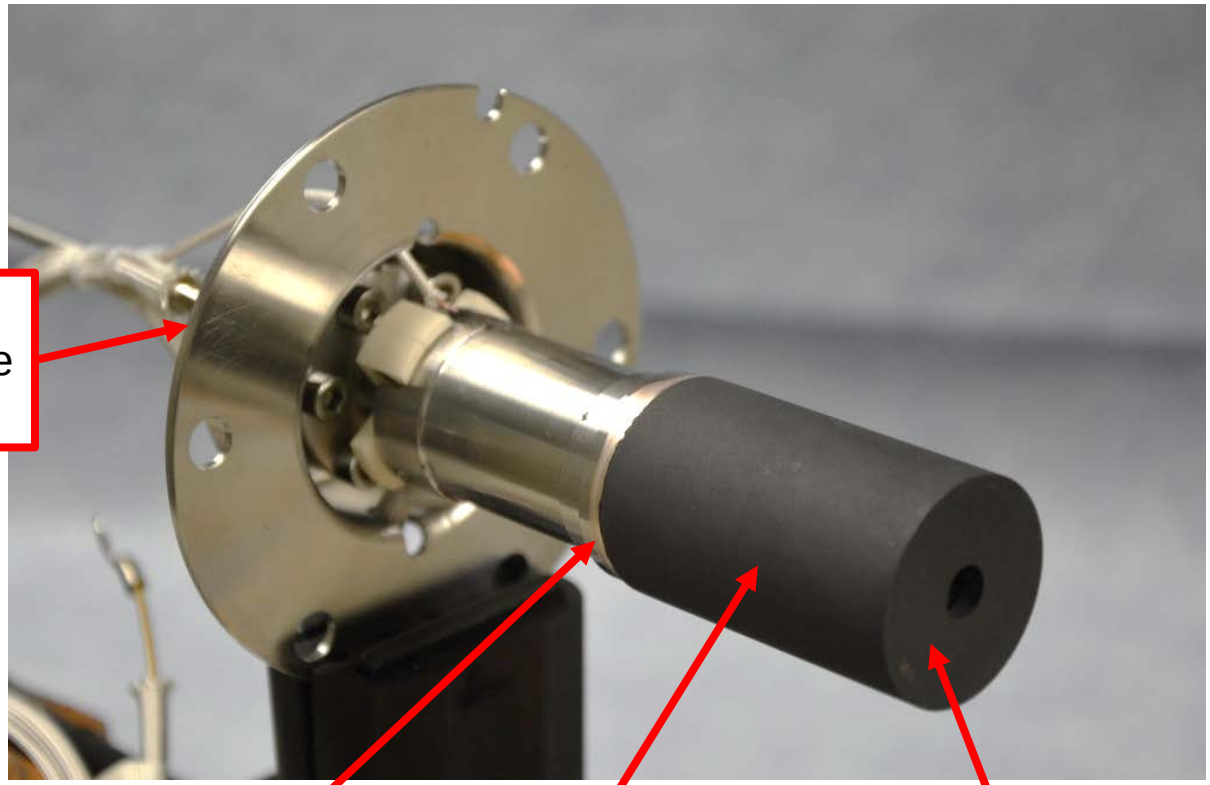
Key design changes of Mark II cathode



Key design changes of Mark II cathode

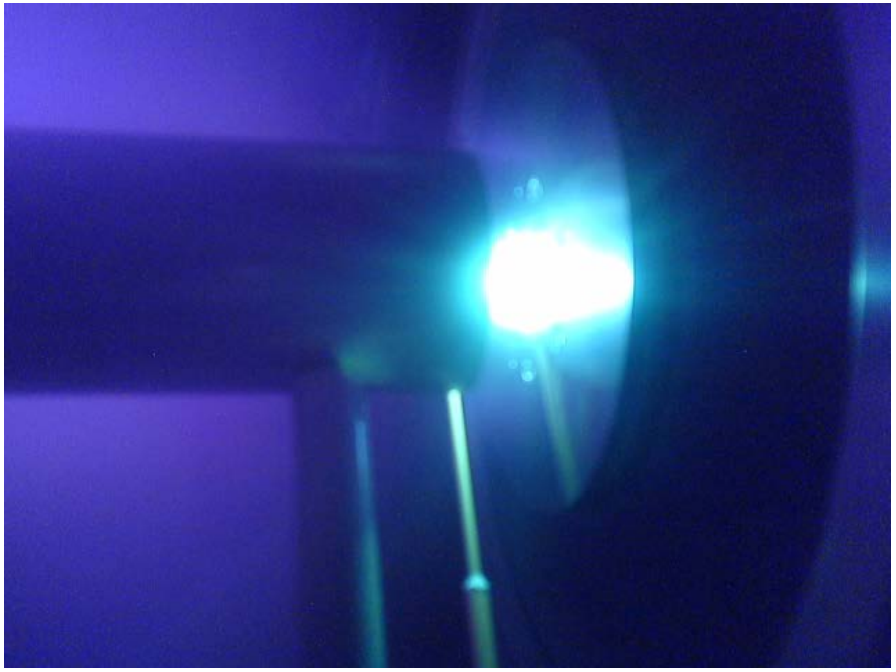


Key design changes of Mark II cathode



Mark II cathode status

- Three Mark II cathodes are being assembled
- Initial characterization of first cathode has been completed
- Next, continued diagnostic work:
  - Plasma plume measurements
  - Temperature mapping



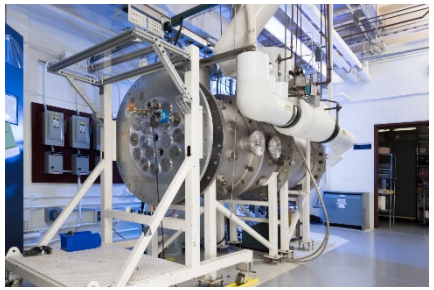
First fire of Mark II cathode in VF-67.

Conclusions

- EDU cathode hardware delivery upcoming
- GRC will be performing cathode testing on EDU units

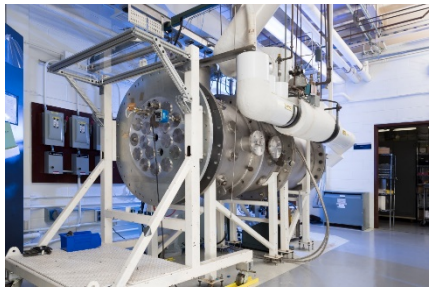
Conclusions

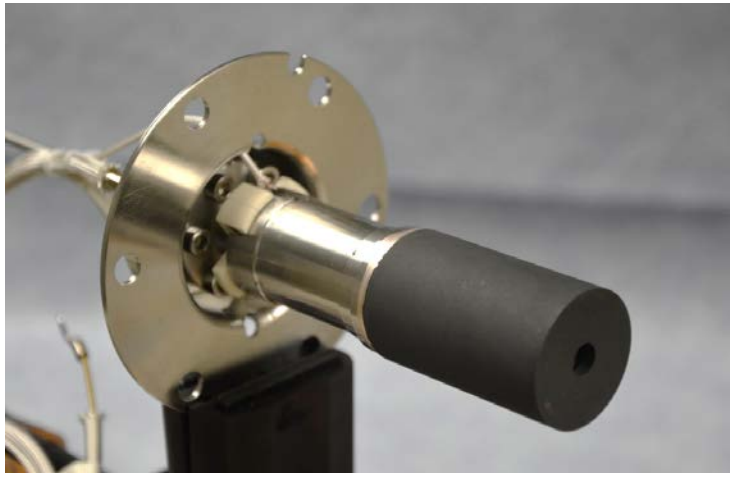
- EDU cathode hardware delivery upcoming
- GRC will be performing cathode testing on EDU units
- Three new facilities for cathode development work
  - VF-67: long-duration wear test (online now)
  - VF-17: short-duration testing (first fire in Aug)
  - VF-1: diagnostics test bed (first fire in Aug)



Conclusions

- EDU cathode hardware delivery upcoming
- GRC will be performing cathode testing on EDU units
- Three new facilities for cathode development work
  - VF-67: long-duration wear test (online now)
  - VF-17: short-duration testing (first fire in Aug)
  - VF-1: diagnostics test bed (first fire in Aug)
- New cathode design developed
  - First unit complete; assembly of units 2 and 3 in progress
  - Will be used for continued checkouts of all three facilities
  - Plasma plume probing and temperature mapping planned





QUESTIONS